BTeV Excerpt from April 2002 PAC Recommendations

E-918 - BTeV (Butler/Stone)

BTeV is a proposed experiment to study mixing, CP violation, and rare decays in beauty and charm particles at the Tevatron in the LHC era. In June 2000, the Director approved the experiment, in accordance with the Physics Advisory Committee recommendations formulated during the week-long Aspen meeting. Since that time, the financial environment has deteriorated. In January 2002, the final report of the HEPAP Subpanel for Long-Range Planning in High Energy Physics (J. Bagger and B. Barish, co-chairs) stated

> *"The BTeV project cannot be funded with the scope and timetable originally envisaged. The collaboration and Fermilab are considering revised plans that, if approved by the Fermilab PAC, should be brought to P5 for evaluation later this year."*

Indeed, the BTeV collaboration has responded with a descoping plan that the Committee finds to be well thought out and that preserves the key features that motivated the initial approval in 2000. After reviewing the revised proposal and re-evaluating the experiment in light of additional information that has emerged in the last two years, the Committee once again recommends Stage I approval for BTeV. Although the composition of the committee has changed substantially since 2000, this recommendation is again unanimous.

BTeV will have a very broad particle physics program, including charm physics, but the primary motivation is the search for new physics through CP violation. The CP violation in the Standard Model is insufficient to explain the matter-antimatter asymmetry of the universe, so this new physics must exist. In this decade, we have an opportunity to thoroughly probe for it in the B meson systems. As discussed in more detail below, BTeV would be unique in having all of the following four key features needed for a definitive mapping of CP violation in the B meson system:

1) A pixel vertex detector that, in addition to providing extremely high quality information offline, is used by the Level 1 trigger to select events with detached vertices. Combined with the high-throughput data acquisition system, this will allow the accumulation of an unbiased, extremely rich sample of events.

2) A particle identification system that will allow identification of kaons and pions, essential to CP violation studies.

3) A high-resolution crystal electromagnetic calorimeter that enables precision study of events containing photons, neutral pions, and etas, including several modes that provide clear tests of Standard Model CP violation.

4) High-rate production of both B_d and B_s mesons, each of which will allow studies of CP violation beyond the capabilities of BaBar and Belle.

By performing these studies at an existing accelerator, BTeV will exploit the large investment that our nation will have made in the Tevatron over two decades.

In the following paragraphs, we review the physics case for BTeV, note the impressive technical progress that the BTeV collaboration has made since its initial approval, and discuss the priority of BTeV within the laboratory program.

The BTeV Physics Case

Tremendous progress has been made in flavor physics since BTeV received Stage I approval in June 2000, and more is anticipated in the next few years. BaBar and Belle have now observed CP violation in B decays and have already measured $\sin 2\beta$ at the 10% level. It is likely that BaBar and Belle will each accumulate in excess of 500 fb^{-1} over the next five to six years, allowing them to make very precise measurements of $\sin 2\beta$ and other Standard Model parameters. Among these is a precise measurement of V_{ub}. This parameter, now known to 20%, should soon be measured to 10%, dominated by theoretical uncertainty. At Fermilab, both CDF and D0 should be able to measure B_s mixing in the near future, or to show that the mixing parameter is outside the Standard Model expectation. These three measurements, taken together, will provide a precision check of the CKM model of CP violation.

At the same time, more information about quark mixing angles and CP violation is within reach. The Committee finds that the current BTeV proposal is compelling as a next-generation B experiment that will measure a number of additional angles and CP asymmetries. These measurements could complete the confirmation of the CKM picture, or they could provide evidence for new sources of CP violation from beyond the Standard Model.

Particularly striking features of the BTeV program are theoretically clean measurements of the CKM angles α and γ. BTeV can also measure the CP angle χ, effectively the phase angle of the B_s mixing matrix. In one year at full performance, BTeV can measure α to ~4 degrees in $B \rightarrow \rho\pi$ and γ to ~8 degrees in $B_s \rightarrow D_sK$. BTeV should also be able to measure χ to 1 degree in $B_s \rightarrow J/\psi\eta$. Each measurement allows a new and stringent test of the CKM model. The Committee notes that definitive measurements of these angles are unlikely to be achieved at e^+e^- B factories or at CDF and D0, even with the large data sets that are expected. Obtaining a large number of independent, theoretically clean measurements is especially important if the predictions of the CKM model are violated. From knowledge of all four angles α, β, γ, and χ, it is possible to diagnose whether violations of the CKM predictions come from new contributions to B_d or B_s mixing or from new tree-level diagrams due to, for example, an extended Higgs sector. BTeV will also carry out a broad program of measurements in rare B_d and B_s decays that will complement the search for new physics via precision CKM tests.

BTeV will run in the same era as LHCb, and so it is appropriate to ask what capabilities BTeV will add to those of LHCb. LHCb starts with a larger B production cross section and a higher ratio of this cross section to the total cross section. However, BTeV has a superior trigger which roughly compensates this advantage. LHCb can make the measurement of γ described

above with a comparable sensitivity, but, because it does not have the excellent electromagnetic calorimeter proposed for BTeV, it cannot compete on B decays with neutrals such as $B \rightarrow \rho\pi$ and $B_s \rightarrow J/\psi\eta$ which give BTeV precise α and χ measurements.

In more general terms, LHCb uses a conventional trigger which concentrates on specific low-multiplicity B decay modes, while BTeV has designed and prototyped an ambitious trigger that will use B decay displaced vertices as its primary criterion. This capability, together with BTeV's excellent electromagnetic calorimetry and particle ID and enormous yields, will allow this experiment to study a broad array of B and B_s decays. BTeV has a broader physics reach than LHCb and should provide definitive measurements of CKM parameters and the most sensitive tests for new physics in the flavor sector.

Modifications to BTeV Since 2000 Approval

BTeV presented an updated technical proposal with a description of a descoped experiment and an update on technical progress. In the revised configuration, the full magnet and vertex detector will be installed, but only one arm will be instrumented with the downstream tracking system, RICH, calorimeter and muon system. The full trigger electronics and computing are maintained. In principle, the loss of the second arm lowers the acceptance and hence the statistics by a factor of two. However, the retention of the full trigger system allows more sophisticated algorithms and thus recovers about 15% of the loss. In addition, the new proposal advocates using the RICH to identify wide-angle leptons; this increases the lepton acceptance substantially. Further cost savings are proposed from recycling the beamline elements from one of the existing interaction regions instead of constructing new final-focus and tune-matching quads and electrostatic separators.

Simulations of the RICH beyond those in the 2000 proposal showed that K/p separation at momenta below 9 GeV/c would not be possible due to pattern recognition problems in separating the faint aerogel rings from the more intense rings from the gas radiator. BTeV proposes to replace the aerogel with a liquid C_5F_{12} radiator, which has the added advantage of producing Cherenkov light at large angle, away from the gas radiator photons, allowing an independent detector using standard photomultiplier tubes.

Detector Development Since 2000 Approval

The collaboration has made significant progress in detector R&D since the 2000 proposal. Pixel sensors were tested in 1999 and achieved the required 5-10 micron resolution. Radiation tolerant 0.25μ CMOS readout electronics have now been beam tested. A system test of the integrated sensor/readout system is planned for the 2002 Fermilab test beam run. The Level 1 trigger has been implemented on FPGA/DSPs, and simulation and timing studies on real devices have been done. General purpose CPUs are also being explored as an alternative to DSPs. The 2000 proposal used a custom network in the DAQ. The collaboration now plans to use several smaller commercial switches, substantially reducing the technical risk.

The BTeV trigger project was considered interesting by the NSF IT research program and has attracted a $5M grant on "Real-Time Embedded Systems." This is a collaboration with computer scientists interested in the construction of fault-tolerant dynamic data systems for a wide variety of applications.

Prototypes of the silicon-strip forward-tracking sensors, based on the CMS design, are being bench tested. Full-length prototypes of the straw tubes exist and are scheduled for beam tests in 2002. The Hybrid Photo-Diode (HPD) used to read out the RICH has been developed, is being bench-tested now, and awaits a beam test next year. Prototype calorimeter lead tungstate crystals have been procured from Bogoroditsk and two vendors in China. Beam tests of a 5x5 array were done at Protvino in 2001 and achieved resolutions of 0.7% at 10 GeV. The support system has been redesigned with significant cost savings. Full "planks" of muon drift tubes will be beam tested this summer.

In summary, full scale prototypes of most detector systems exist and will be beam tested by the end of the year. Though the BTeV detector is a significant technical challenge, the excellent progress in detector R&D enhances the Committee's confidence concerning the technical implementation of the project.

Priorities and Schedule Constraints

In reaffirming our recommendation for Stage I approval, the Committee also reaffirms its view of the priority of BTeV within the Laboratory program as stated in the recommendations from the June 2000 PAC Meeting:

> *"The Committee had extensive discussions of the impact of BTeV on the ability of the Laboratory to carry out the other parts of its physics program. The Committee reiterates that the highest priority of the Laboratory in the coming decade is Run II of the Tevatron, and the most exciting goal of this program is the discovery of the Higgs boson or other new physics. For this, it is essential that the CDF and D0 collaborations write to tape the highest possible integrated luminosity. The Laboratory's efforts to develop, construct and install BTeV absolutely must not be allowed to interfere with the discovery potential of Run II. The Committee also reiterates the importance of the NuMI/MINOS program, which should continue to be supported as planned."*

The diversion of resources away from BTeV is a direct result of those priorities.

In June 2001, the Laboratory also granted Stage I approval to the CKM experiment. The Committee's June 2001 report stated:

> *"In judging relative priorities after Run II, the Committee rated CKM behind the physics programs of MINOS and BTeV. Noting that both these experiments have competition from others, CKM must not prevent MINOS and BTeV from reaching their physics goals in a timely fashion."*

This assessment of the priority remains the position of the Committee, and such a priority constrains the schedule of BTeV's construction and running. The Laboratory's projections show that the first large increment of construction funding can come no earlier than FY2005, after NuMI construction ramps down and the Run IIb detector upgrades near completion. The BTeV collaboration presented a construction schedule, with a funding profile consistent with the Laboratory's projections, that indicated completion in FY2008. It is possible that Run IIb may continue beyond this date, and BTeV can expect no significant luminosity before Run IIb ends. This delay would be exacerbated by the time to move the interaction-region optics and might put BTeV at an initial disadvantage with respect to LHCb. While BTeV can commission many of its subsystems with beam halo on a wire target as they are installed, the Committee encourages, as resources allow, the search for an interaction-region option that would avoid these further delays of BTeV.

This timeframe for BTeV brings up another issue of priority. The U.S. high-energy physics community proposes to take part in an international effort to build a Linear Collider, and the Laboratory has proposed that Fermilab be considered as a possible U.S. site for this facility. The Committee believes that having the LC at Fermilab would be of great benefit to science, our field, and our national program. The Committee recommends approval of BTeV with the understanding that it must not, and with the belief that it will not, adversely affect the prospects for the LC project.